Research in organic waste as resources: How to implement circular bio-economy in the urban context?

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Research in organic waste as resources: How to implement circular bio-economy in the urban context?

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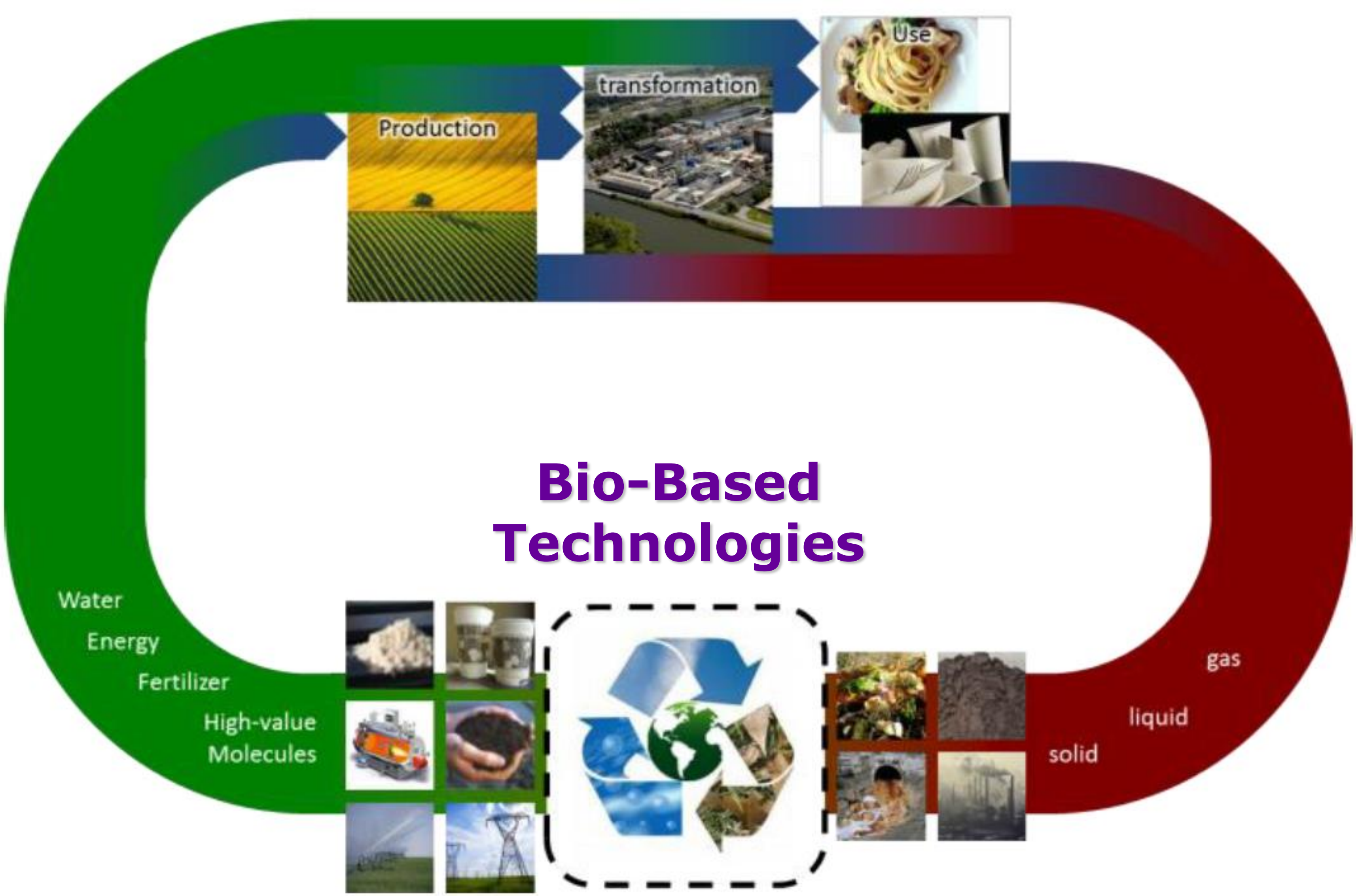
Agenda

- Introduction to Circular Bio-Economy
- Overview of emerging approaches to recover resources
- Technology selection

What is circular Bio-economy?



Motivation?

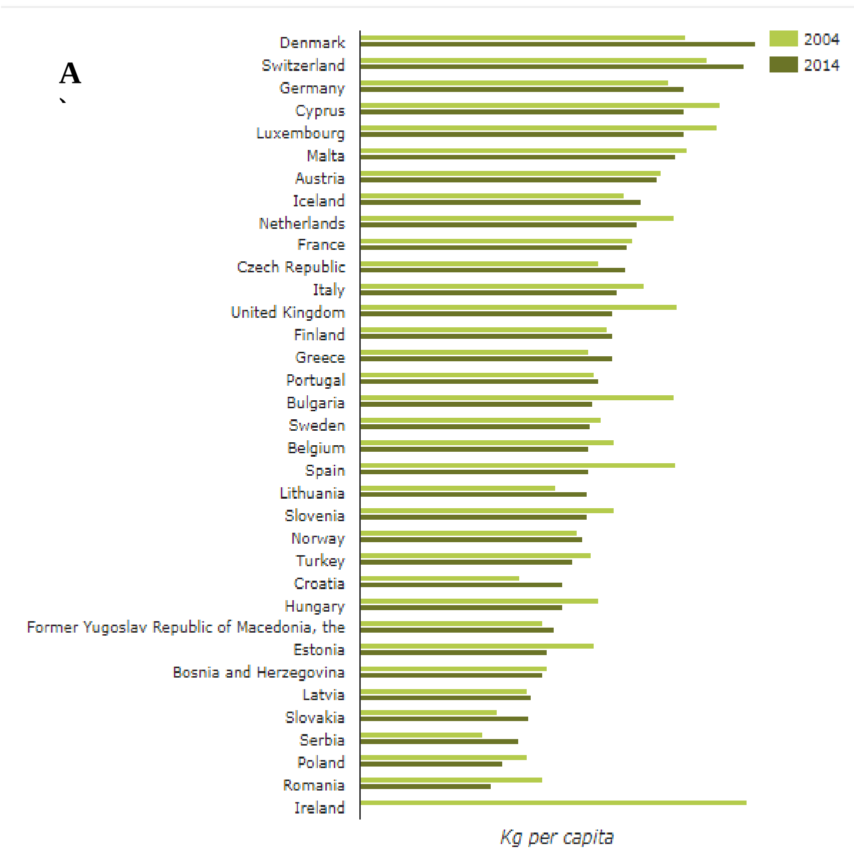
Sustainability goals for 2030

Why do we need to recover resources?

- Present and future regulations on GHG footprint from waste treatment facilities
  - Nutrient recovery as a mean to reduce carbon footprint
- Old infrastructure
  - Opportunity to include resource recovery in the retrofitting

Overview of waste production and recycling in Europe

- Municipal solid waste in 2020 → **271 M-t**
- Urban biowaste → **96 M-t**



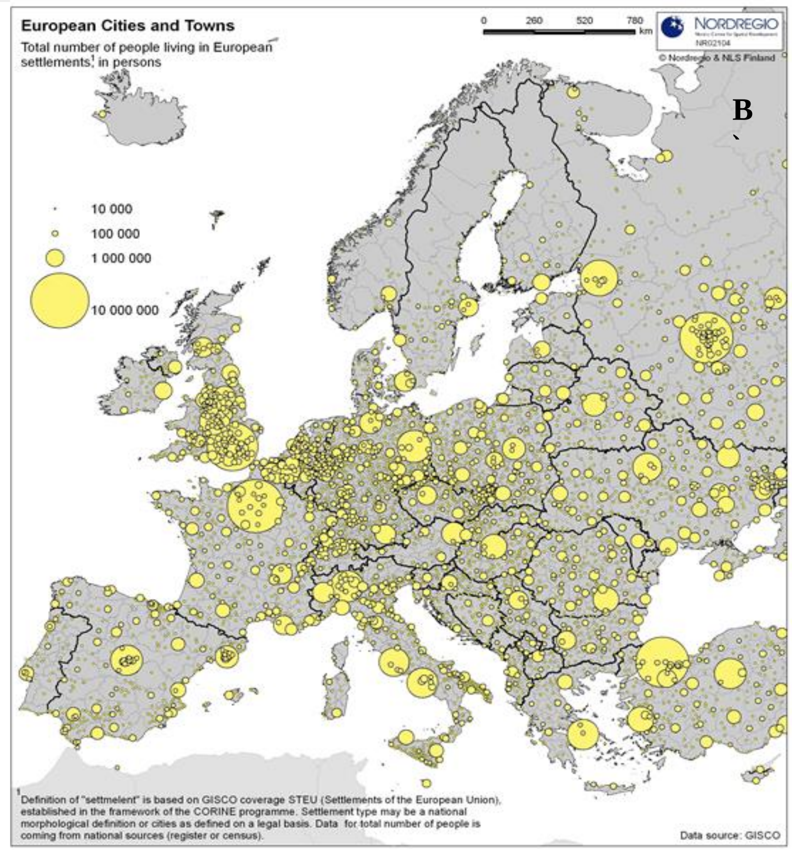
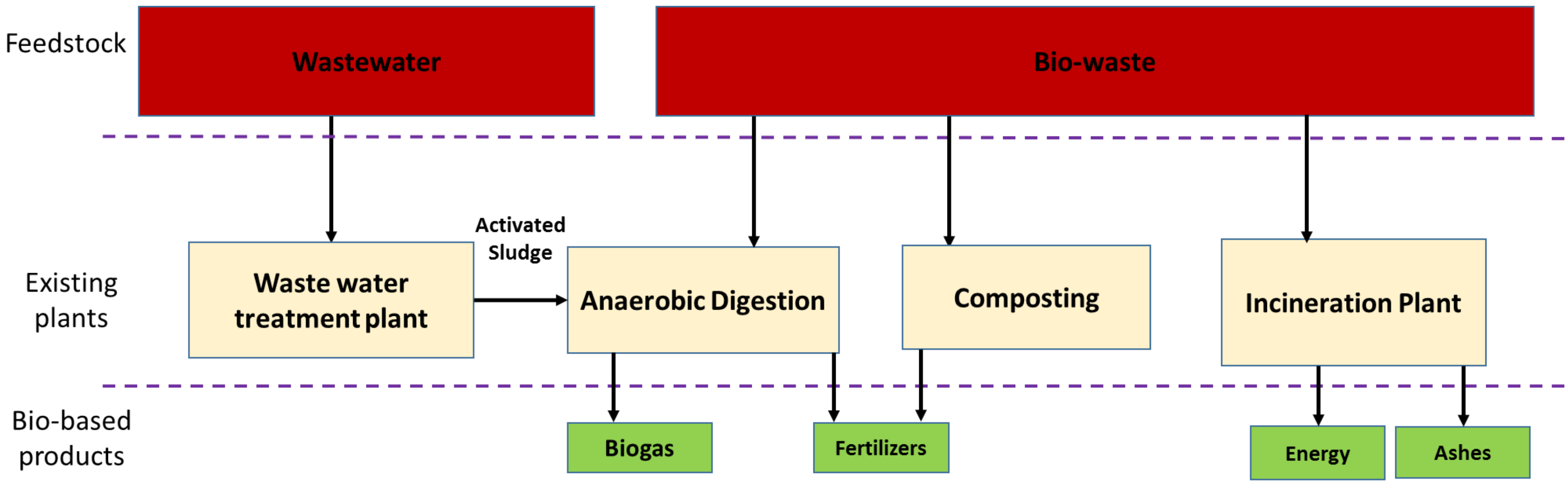
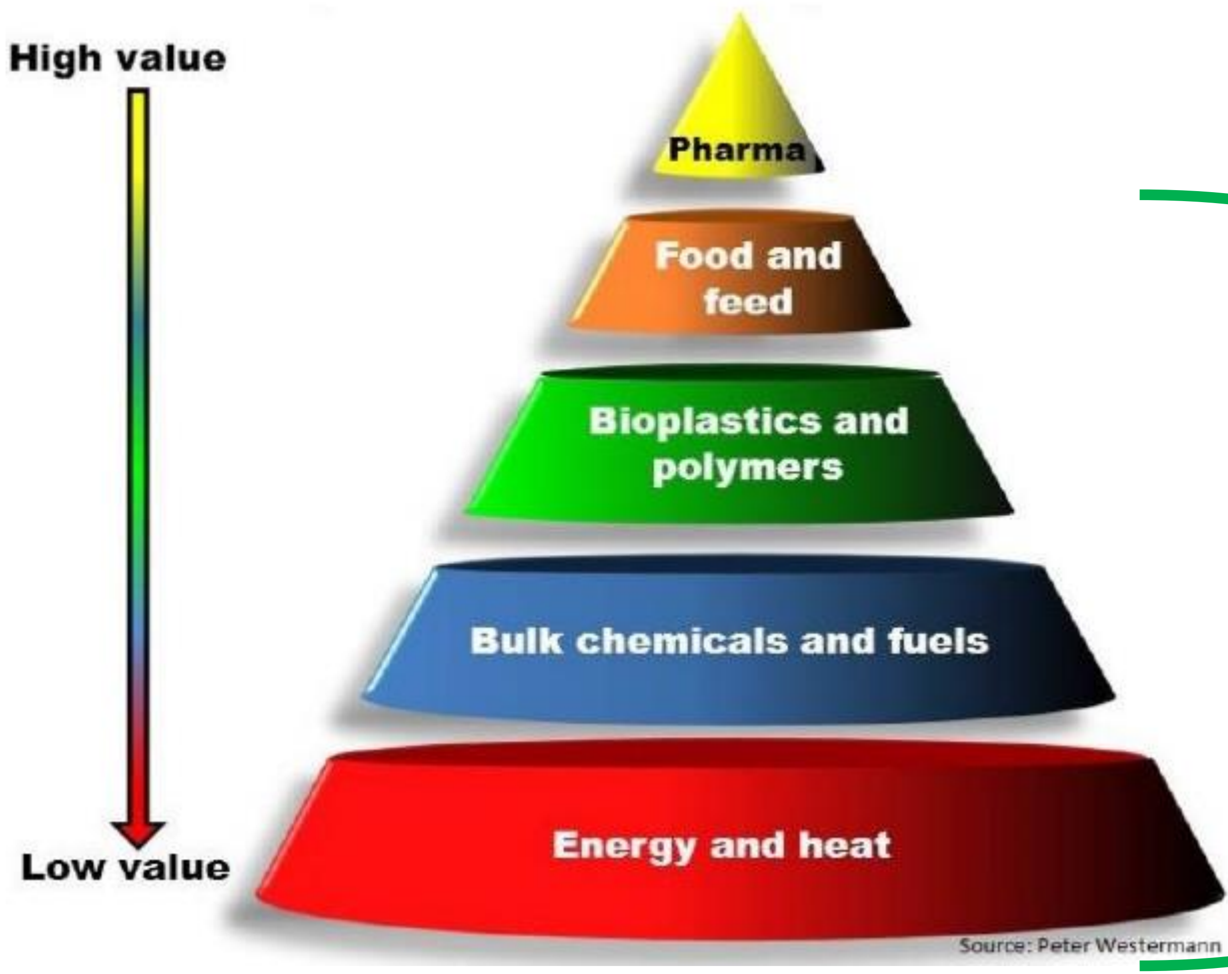


Fig 11. A) Bio-waste recycled per capita; B) population in European municipalities.

Traditional Organic Waste Managment



Classification of Bio-products

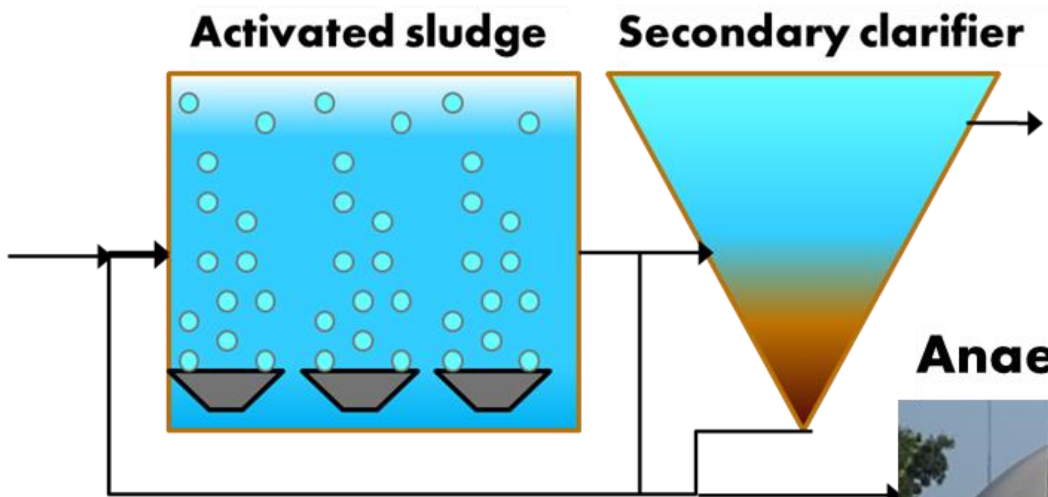


Recovery from Waste

Improving conventional approaches – biogas and fertilizers

Wastewater treatment– what's new?
Carbon recovery from sewage

- Traditional water treatment plant
- Less than 10% organic carbon recovery!!



Anaerobic digester

$$C_{18}H_{19}O_9N + 0{,}74NH_3 + 8{,}8O_2 \rightarrow 1.74Biomass + 9{,}3CO_2 + 4{,}52H_2\,O$$

Up to 40% recovered!

Wastewater treatment– what's new?
Carbon recovery from sewage

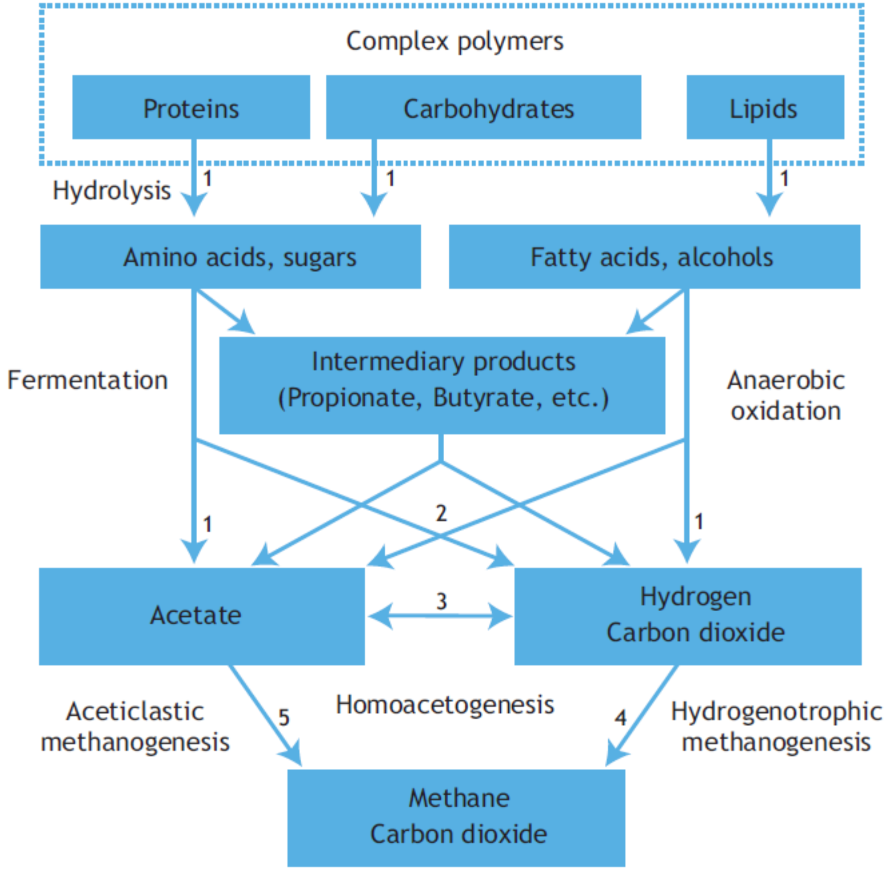
- Direct water filtration

Chemical enhanced filtration

Biogas production – what's new?
Biogas Upgrading

Biogas composition and valorization:

- 60% of CH_4 and 40% CO_2
- Co-generation plants to produce heat and electricity
- Biogas upgrading → CO_2 removal to achieve >95% CH_4 concentration
  - Natural gas grit
  - Vehicle fuel

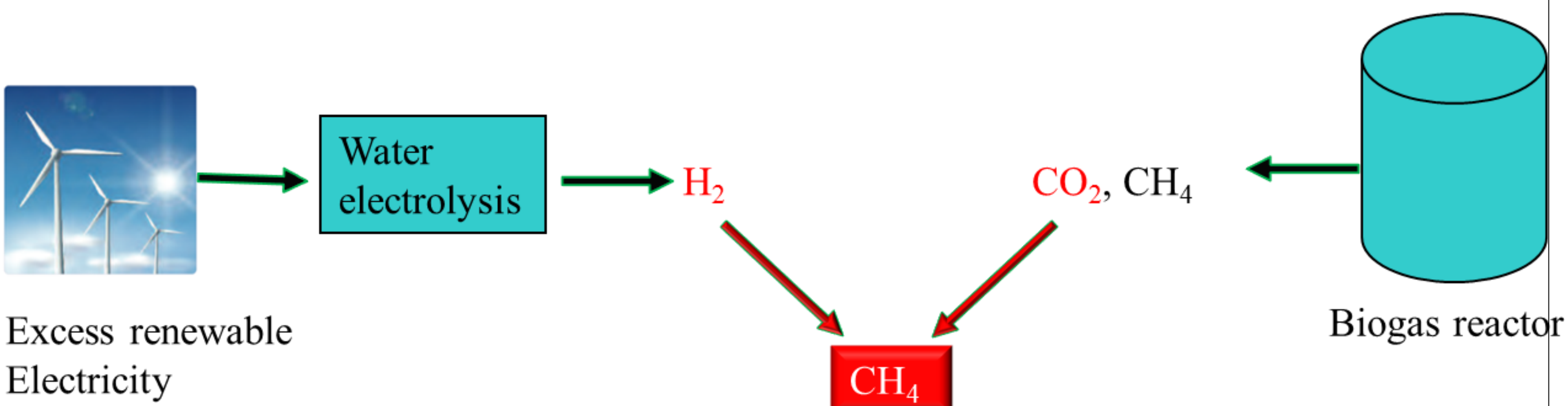


Biogas production – what's new?
Biogas Upgrading

- **CO_2** together with **H_2** could be used by **hydrogenotrophic methanogens** for methane production.

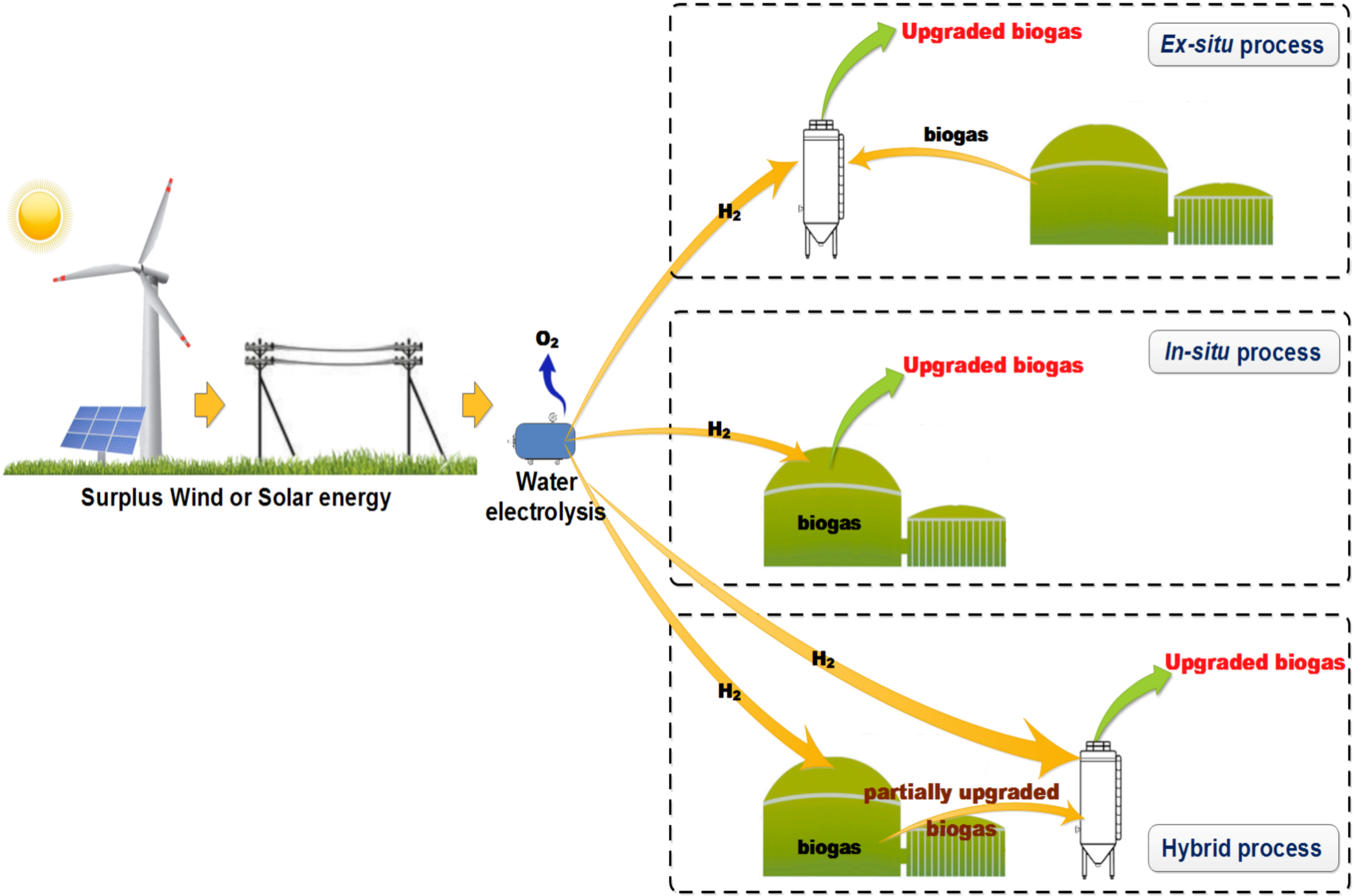
$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

- **H_2** could be obtained by electrolysis of water using the **surplus electricity** from eg. wind mills, or photovoltaics.

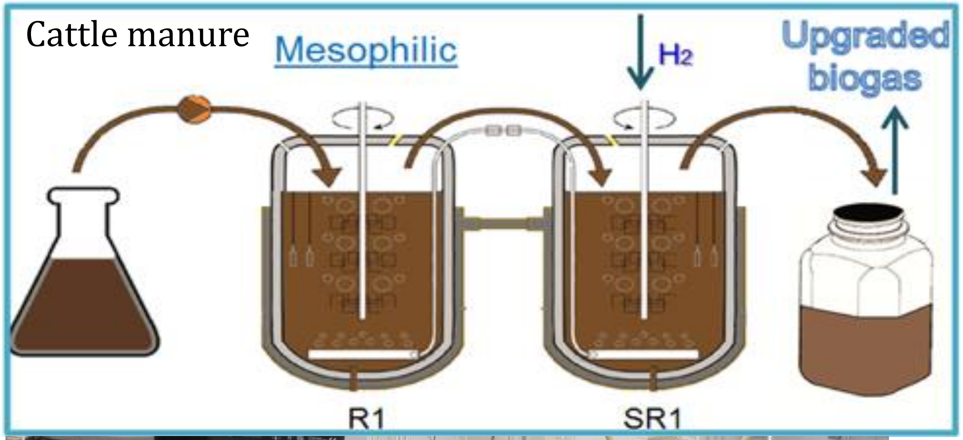


Surplus Energy/Energy Storage?

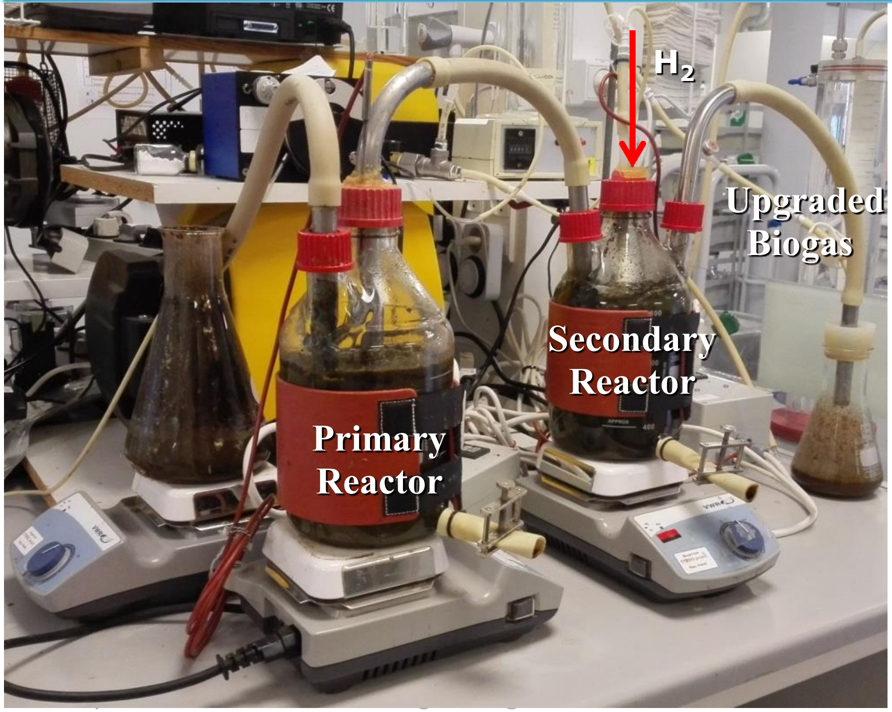
Biogas production – what's new?
Biological biogas Upgrading

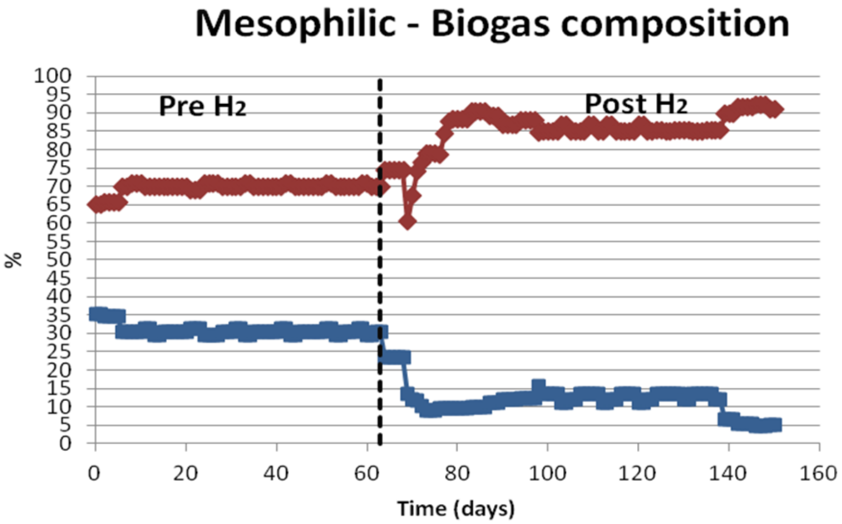


Biogas production – what's new?
Biological biogas Upgrading



Technical challenge: limitations in injection of H_2 using metal diffusers





Biogas production – what's new?
Biological biogas Upgrading

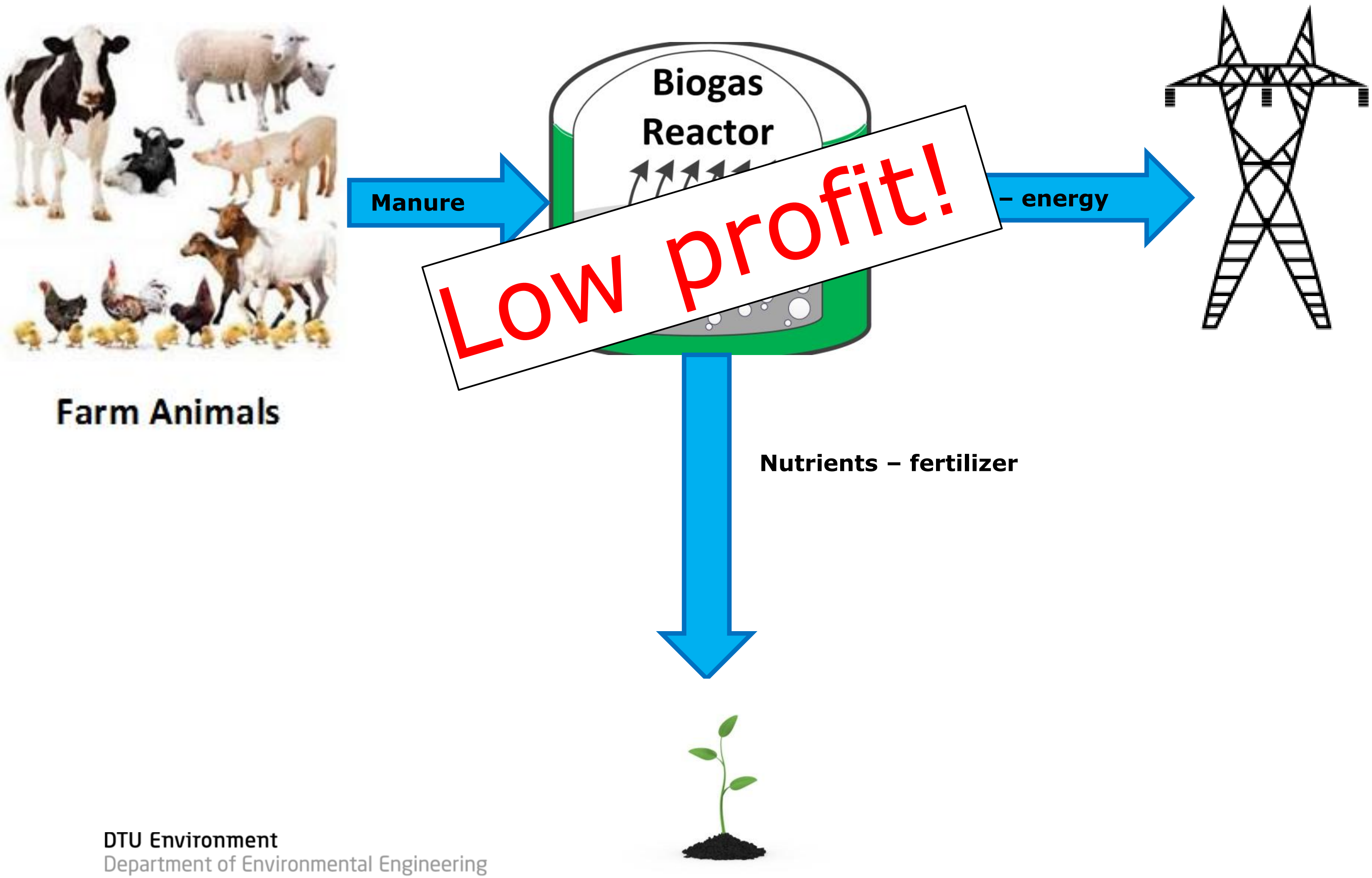
Pilot Scale-VARGA Project

Full Scale: in 2 to 3 years

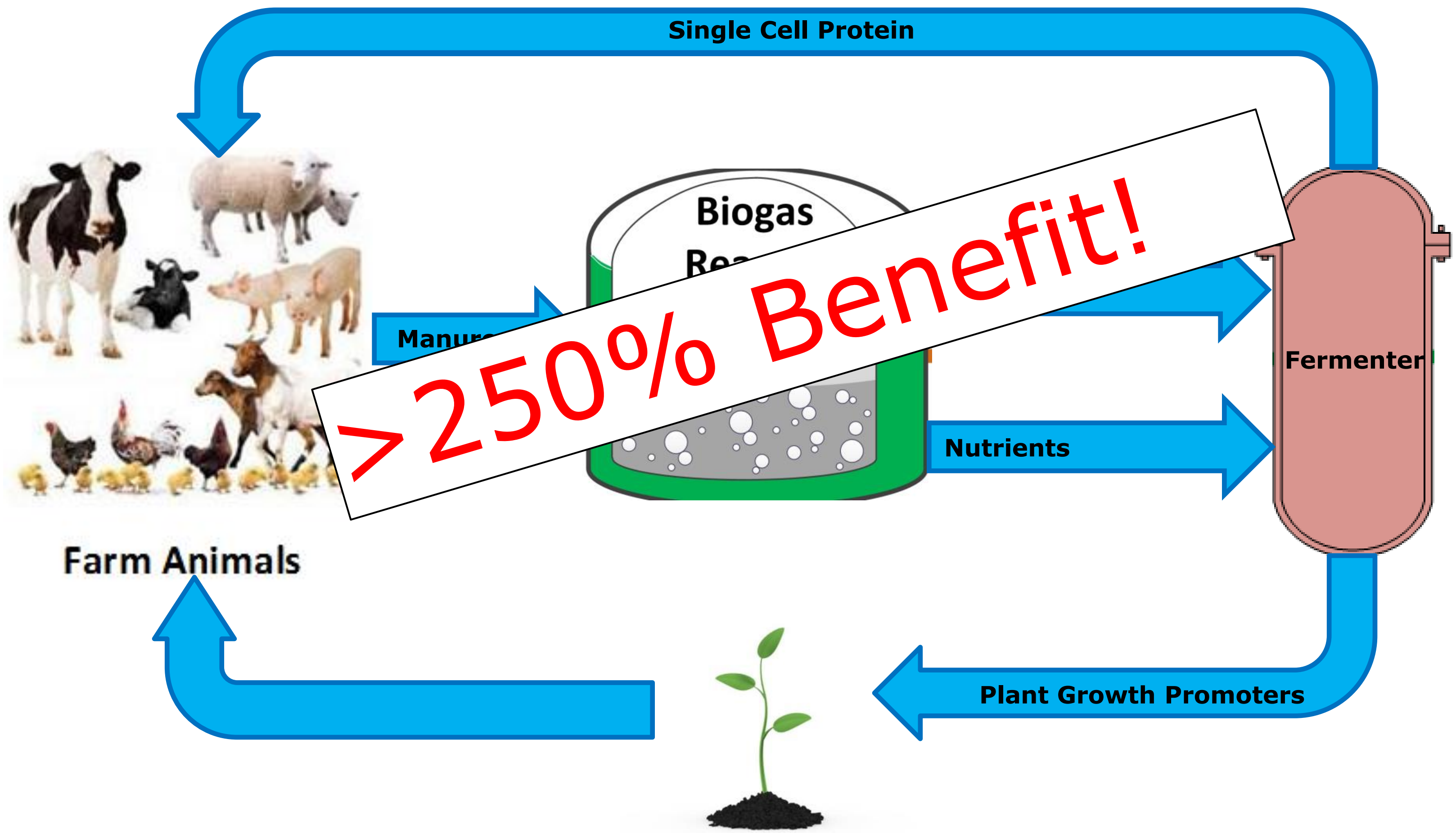
At Avedøre Rensningsanlæg we demonstrate both the bioaumentation and the upgrading technology

Beyond biogas and fertilizers – novel resource recovery strategies

Nutrient Management – Traditional approach



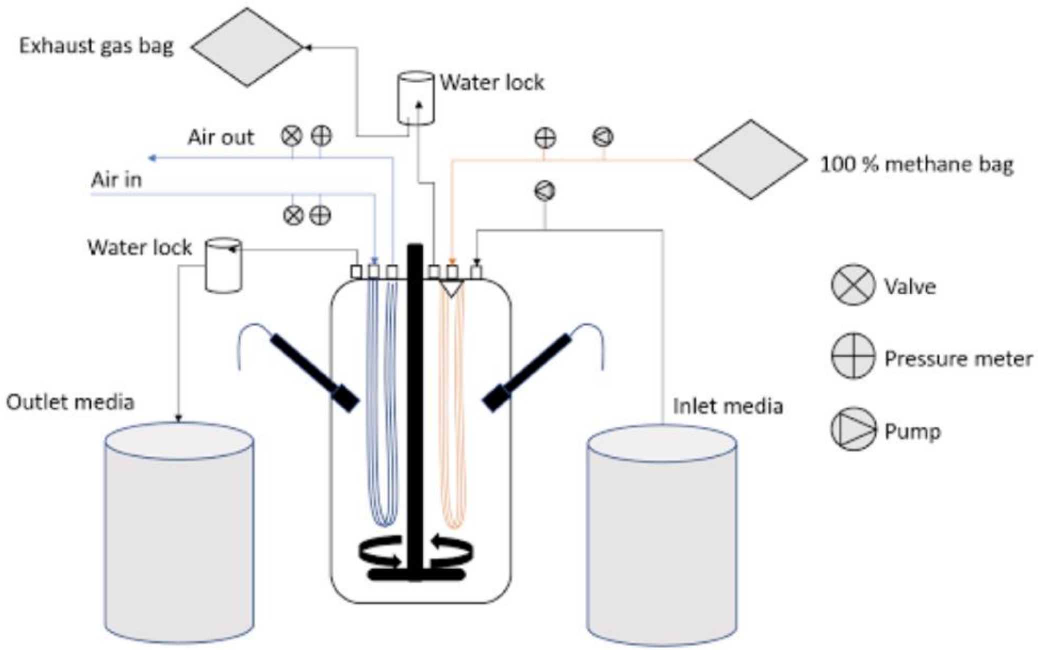
Nutrient Management – Nutrient Upcycling and Reuse in Agriculture



Examples of nutrient valorisation as Single Cell Protein – Gas supply through membranes

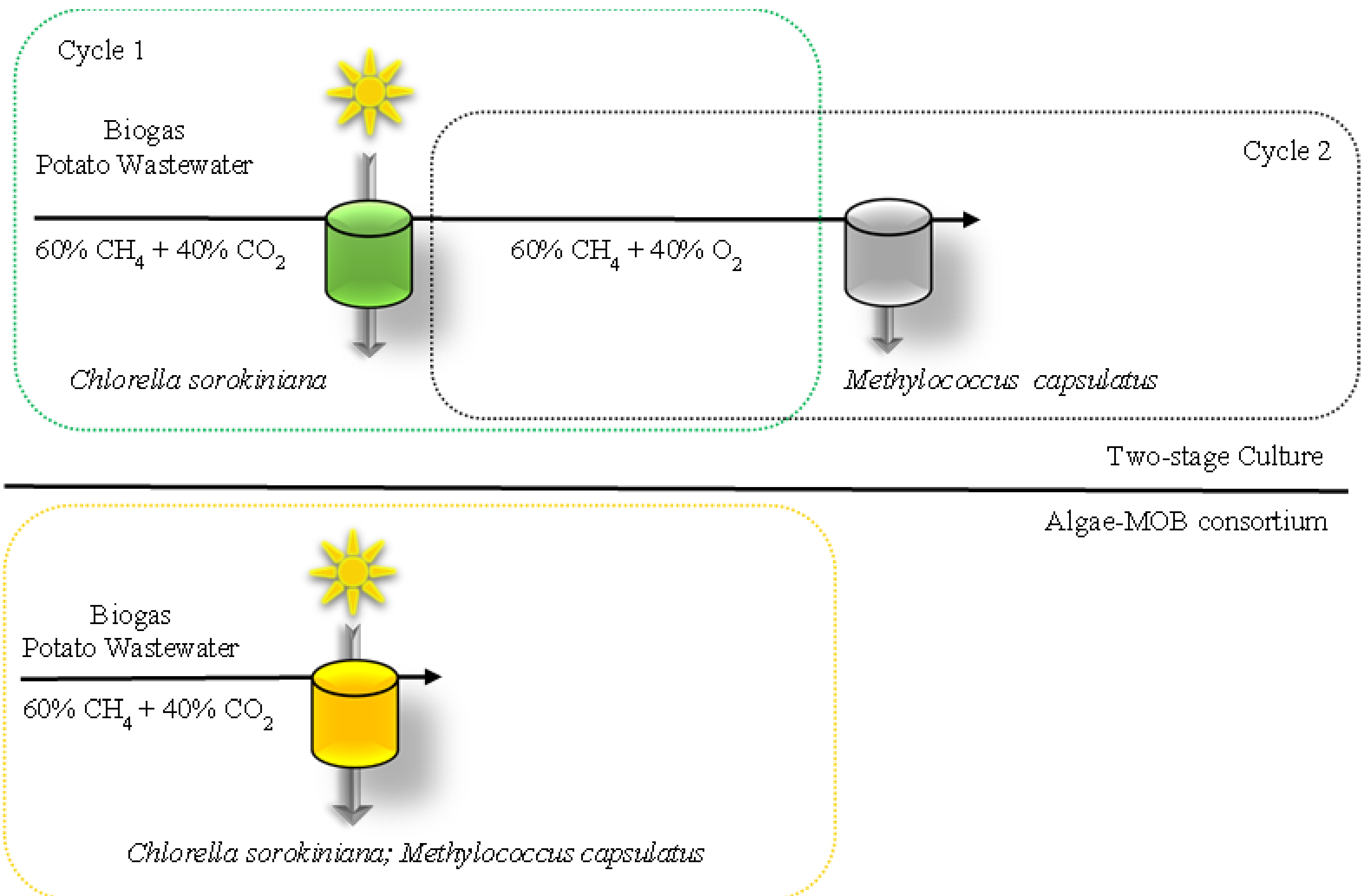
<u>M</u>ethane **<u>O</u>**xidizing **<u>B</u>**acteria store proteins (EU approved as feed ingredient!)

<u>Technical challenge:</u> gas bubbling produces explosive atmospheres!



Examples of nutrient valorisation as Single Cell Protein

Co-cultivation of algae and methanotrophs



Examples of nutrient valorisation as Single Cell Protein

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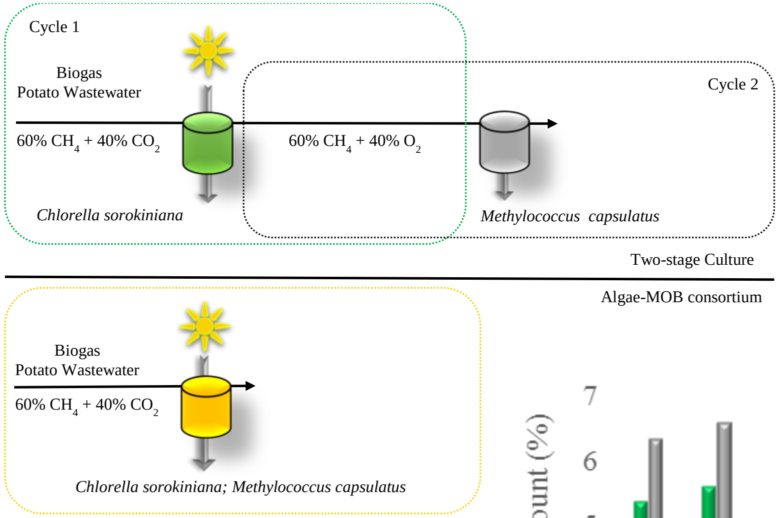
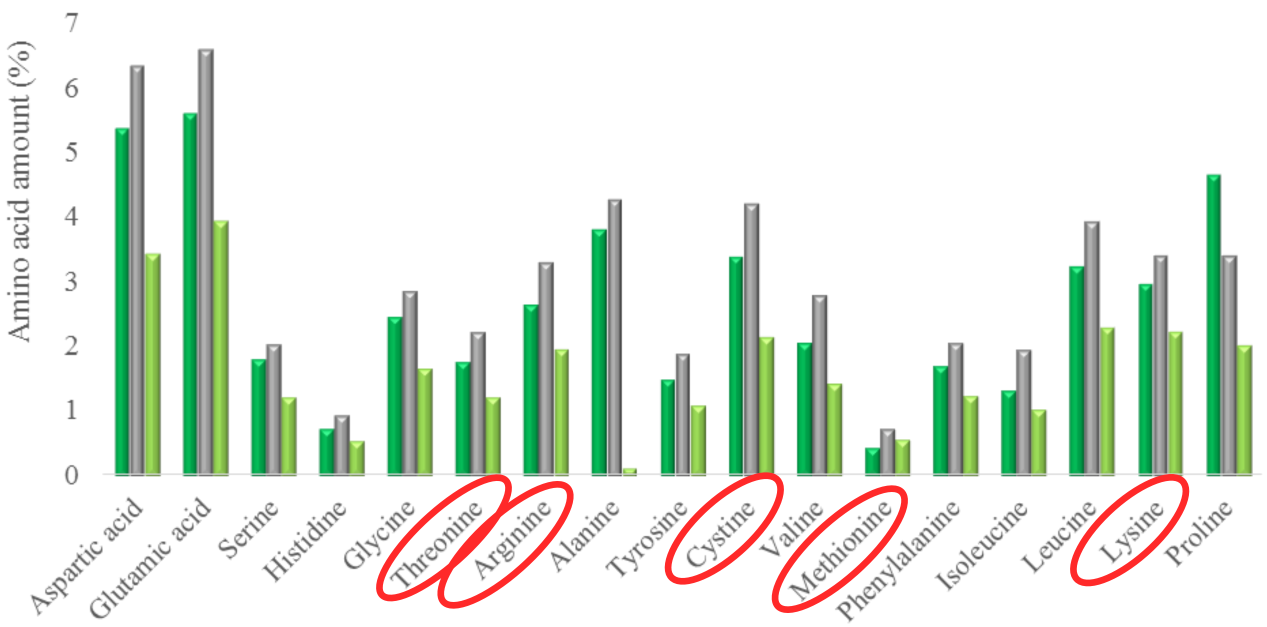


Contains the essential amino acids for chicken



Rasouli et al., 2018 (*BEJ*)

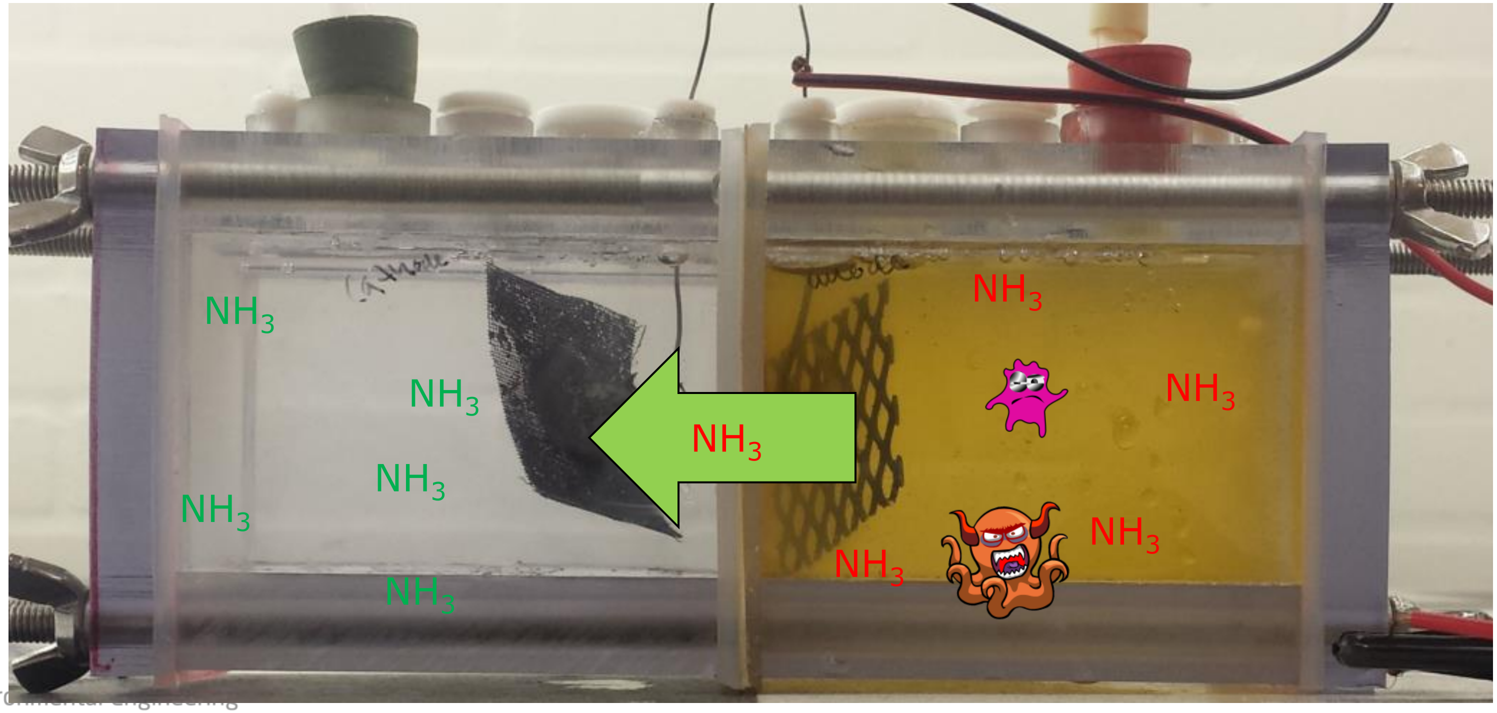
What happens with the real pollutants?

Who are the bad guys?

- Heavy metals
- Impurities
- Pathogens
- Pharmaceuticals
- Antibiotic resistance genes

How do we get read of them?

- Membrane filtration
- Bio-electrochemical systems

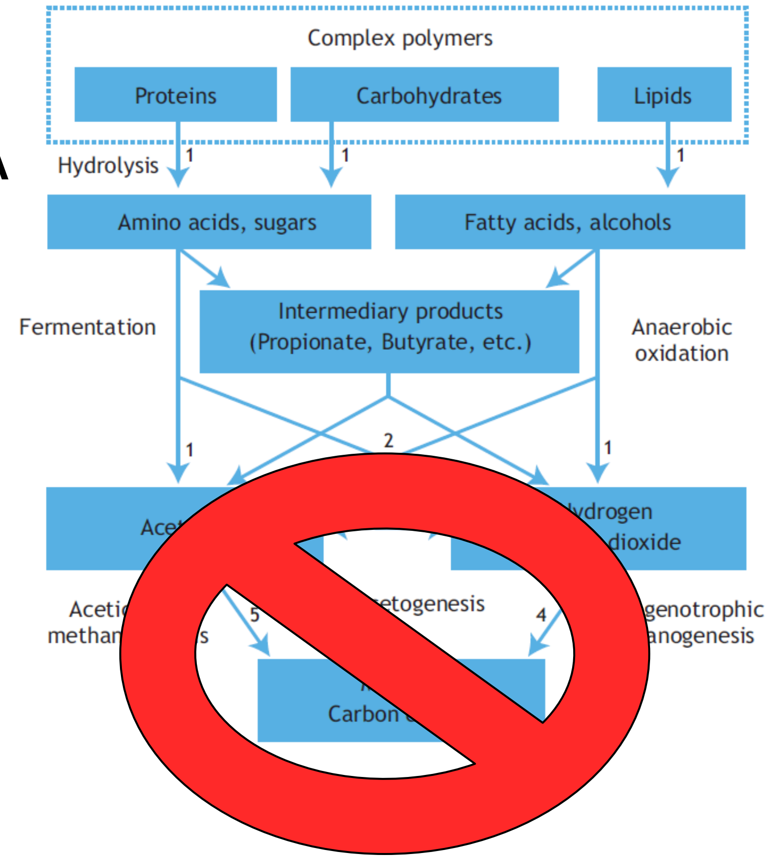


Carbon valorization – Platform chemicals

<u>What is a platform chemical?</u>:small molecules derived from biomass that could be utilized as building blocks for higher-value chemicals (e.g., solvents) and materials (e.g., polymers)

<u>Volatile fatty acids</u>

- Fermentation of bio-waste
- Main challenge: purity of the VFA
- Example of propionate
  - additive or flavoring agent
  - mold and bacteria inhibitors in food products
  - building block for herbicides, vitamin pharmaceuticals, dyes, plastics, cosmetics…
  - de-icing salts



BIOSUCCESS – A Unique Technology

Simultaneous biomethane and biosuccinic acid production

$$7C_6H_{12}O_6 + 6CO_2 \rightarrow 12C_4H_6O_4 + 6H_2O$$

Arabinose

Fructose, Fucose

Galactose, Glucose

Glycerol (Diesel production)

Lactose

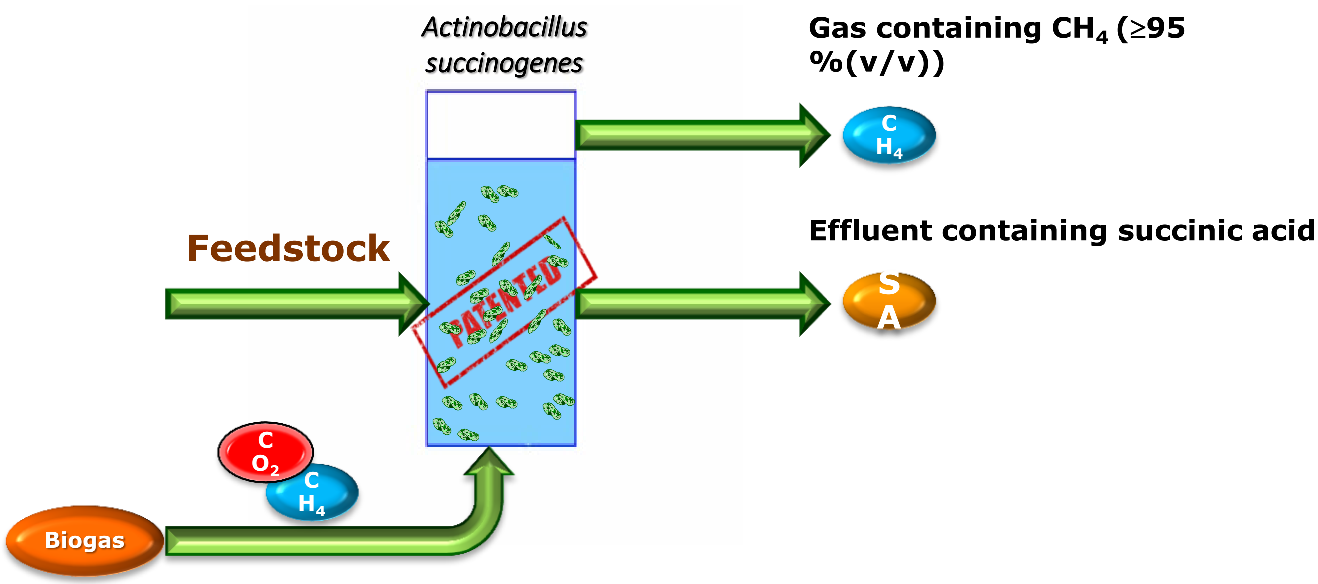
Maltose, Mannitol, Mannose

Sorbitol

Sucrose (NS)

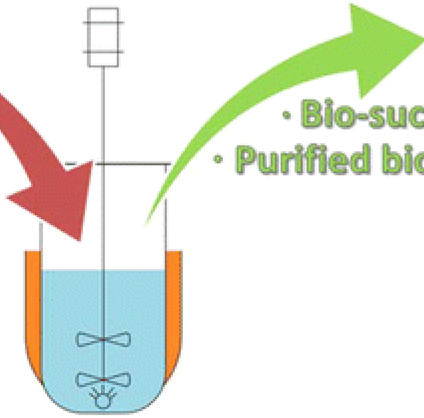
Xylose

Glycerol

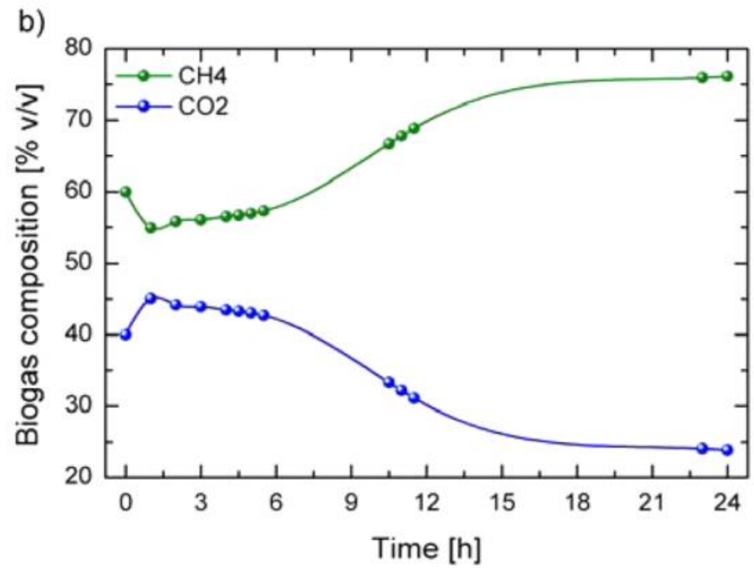


Biogas Upgrading and Bio-Succinic Acid

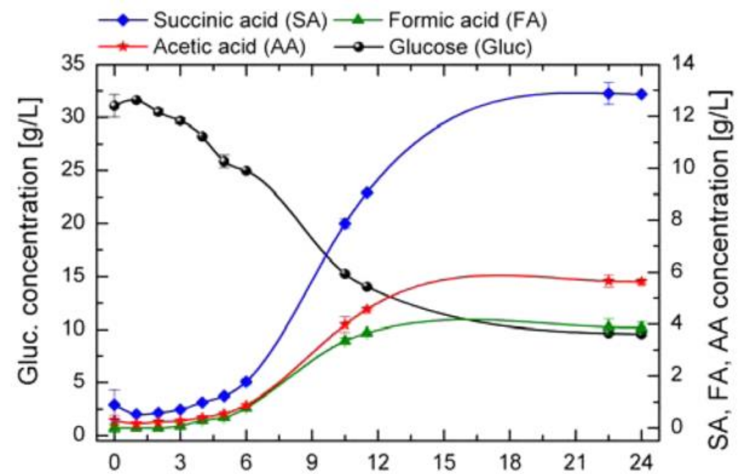
- Biogas (CO_2 source)
- Mono-saccharides
- *Actinobacillus succinogenes*



- Bio-succinic acid
- Purified bio-methane

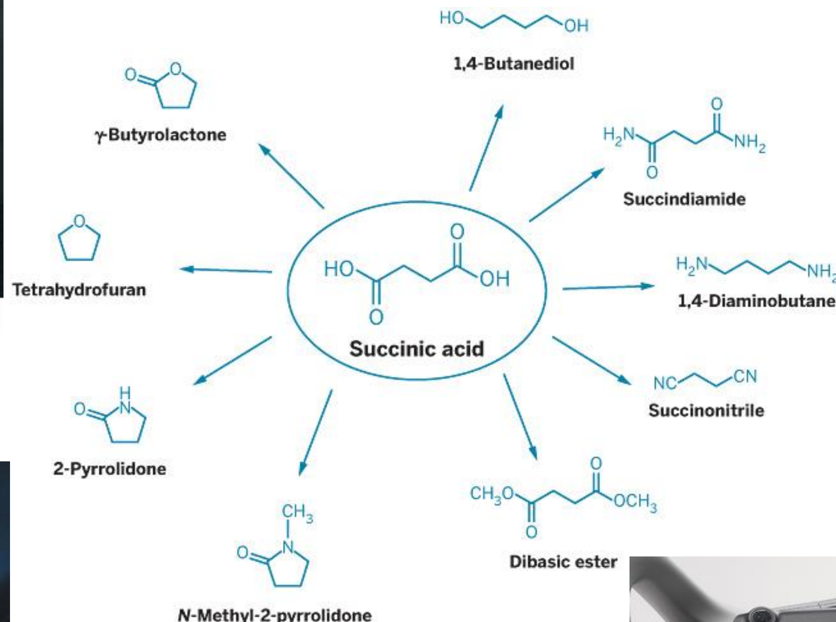


Nordic Sugar
Member of Nordzucker Group

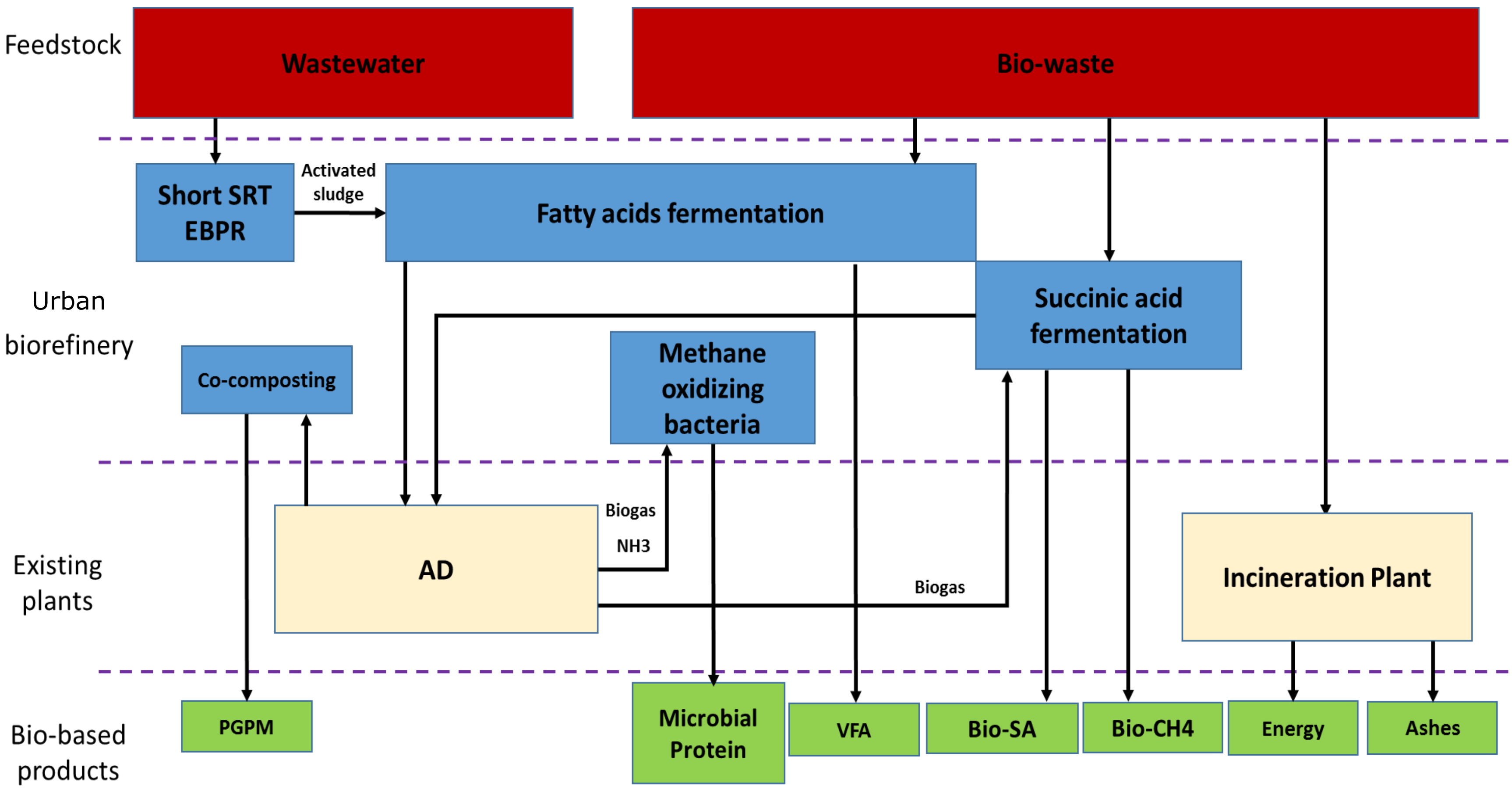


Succinic Acid

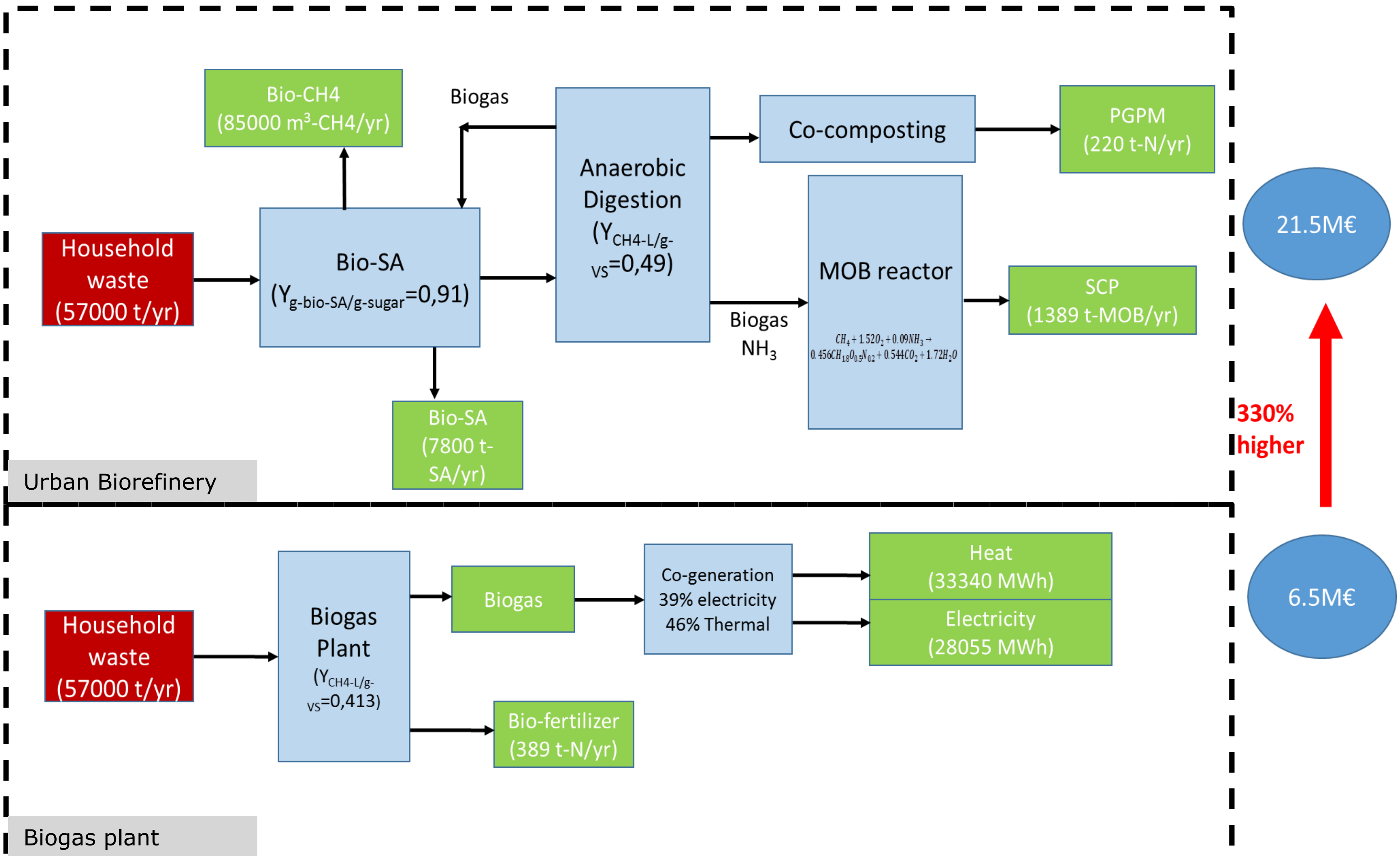
- Succinic acid applications include:
  - Pharmaceuticals, coatings, biopolymers, green solvents



Urban biorefineries

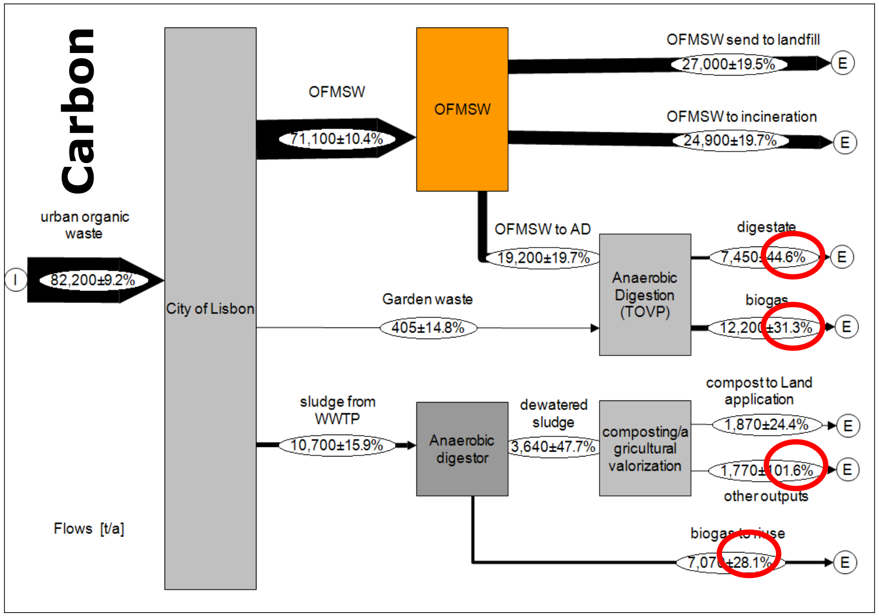


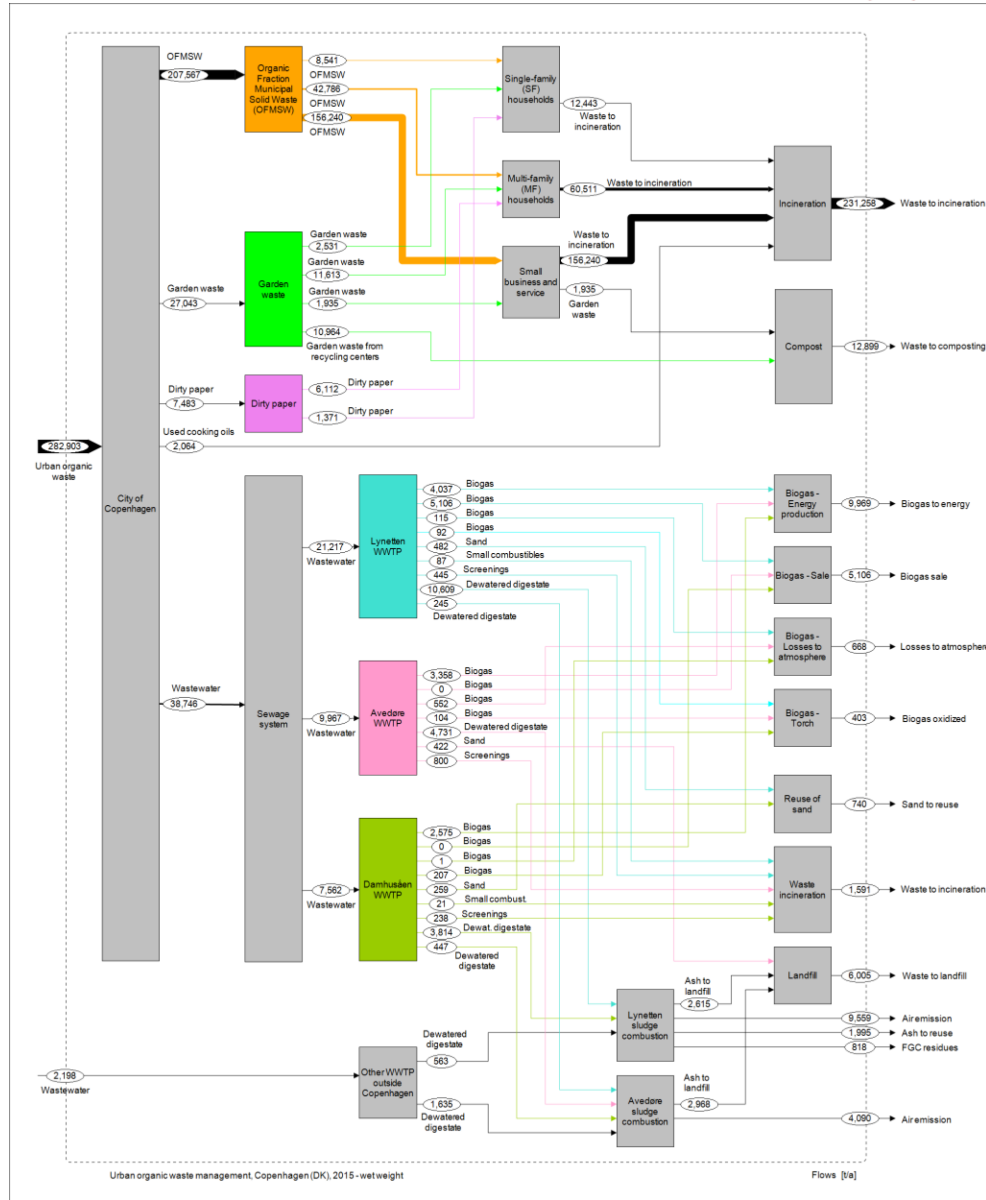
The example of Copenhagen municipality



How to select best resource recovery strategy?

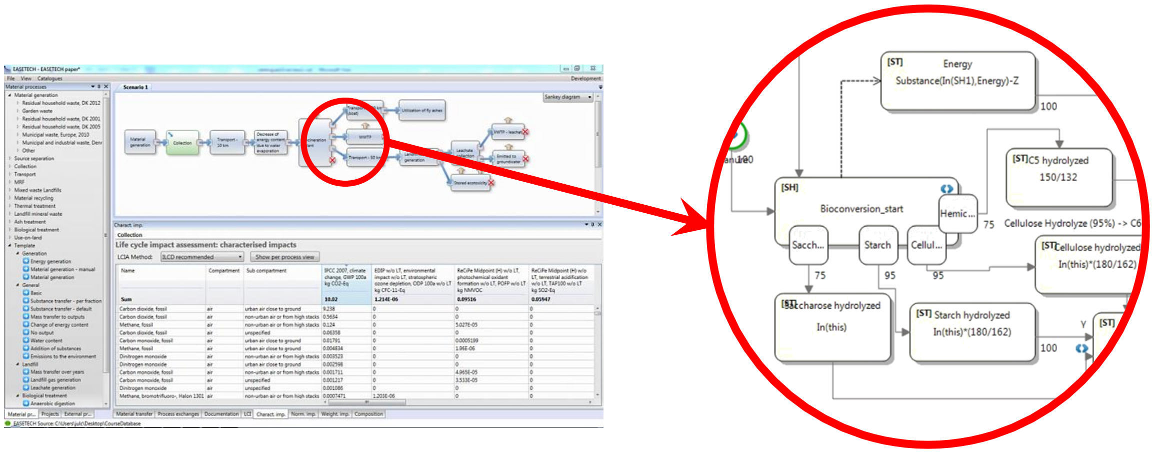
Resource mapping





- Full system:
  - Materials
  - Energy
  - Substances
- Uncertainty characterization

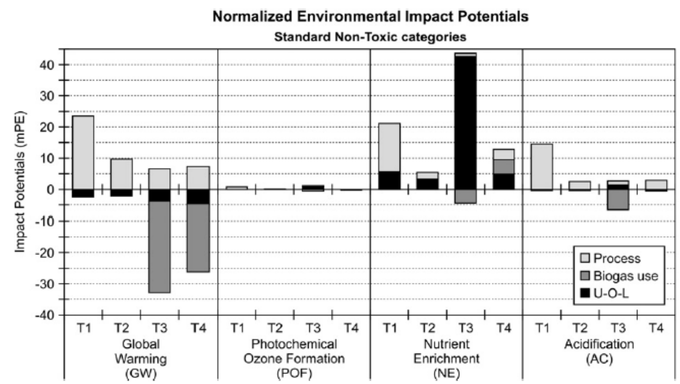
Sustainability Assessment of Residual Bioresource Engineering

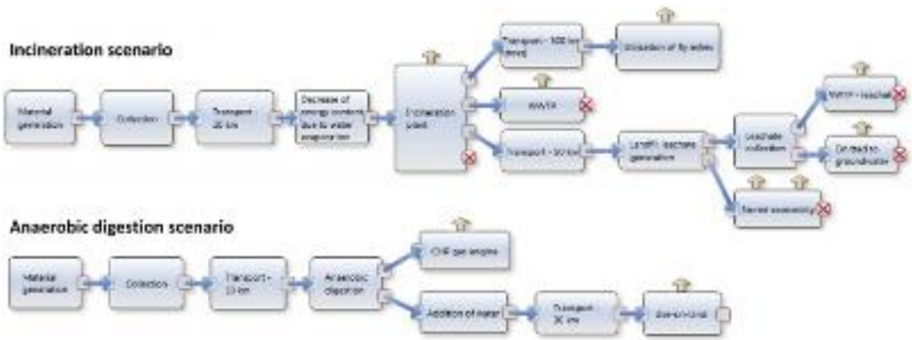


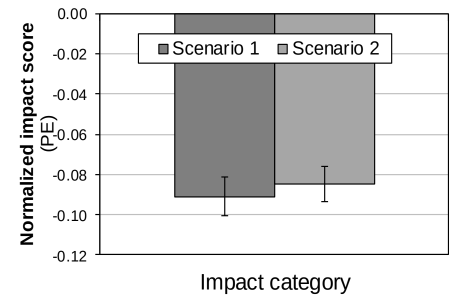
- LCA and LCC: EASETECH, a DTU developed model
- Assessment of full value-chain with focus on residual resources
- Process-oriented modelling of technologies reflecting actual conversion pathways
- Integrated conversion and recovery of multiple outputs based on properties of substrates
- Optimal system integration and process configuration
- Identification of critical process parameters

Life Cycle Assessment (LCA) and Costing (LCC)

- Waste composition
- Use of energy/materials
- Process parameters
- Emissions





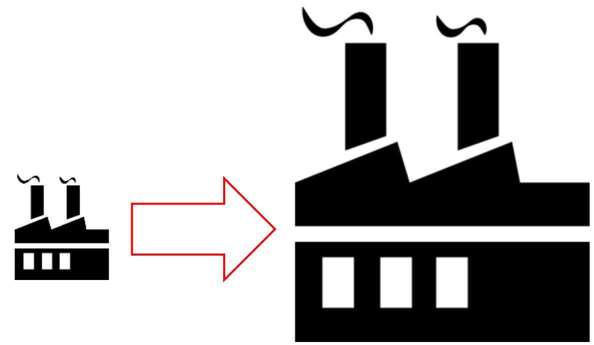


- Energy system
- Market of products
- Background conditions

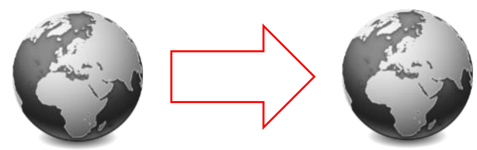
- Comparative performance
- Hotspots
- Uncertainties

Challenges

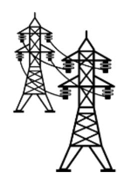
- Upscaling of technology



- Local conditions
- Scope:



  - Technology data
  - Substitutions
  - Framework conditions:
    - Energy mix
    - Fossil vs biomass-based plastic



  - Production of mineral fertilizers
  - Capital costs

Acknowledgement

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